US AIR FORCE EarthRadar FOR UXO CLEANUP

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ABSTRACT

Millions of acres of Government owned properties are contaminated with UXO. The need exists to accurately and reliably assess the extent of contamination and to economically remediate the contaminated areas. UXO may be found on/and below ground surface as well as marine environments. As a result of war, military training and weapon testing, UXO contamination poses a threat to the general public and military personnel. This threat becomes more serious on or near the active installations seeking to clean their ranges, at sites designated for base realignment and closure (BRAC) and to Formerly Used Defense Sites (FUDS). In addition, the millions of mines deployed each year also fall under the general UXO category. In order to meet the ASC/WMGB requirements in cleaning up test ranges after munitions test, a GPR sensor technology, refer to as "EarthRadar" system, was developed by Bakhtar Associates. Its capability was demonstrated and verified under field conditions. This paper further elaborates on the EarthRadar capability for detection of metalic and plastic targets in adverse ground which include salt-saturated soil and ocean water with high salinity. On-going research activities, development of the next generation antennae and a 3-D volumetric reconstruction model/program to enhance the EarthRadar capability for target/clutter discrimination are briefly discussed. Such capability can eliminate false alarms associated with target identification and significantly reduce the cost of remediation.

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INTRODUCTION

There are two possible ways in which the electromagnetic waves may be used in searching for subsurface objects. They are differentiated on the basis of their operating frequency. At high frequencies, above 1 MHz, electromagnetic waves can be directed to propagate into the ground in a straight line to depths which vary from a few centimeters to tens of meters depending on the electrical conductivity of the terrain. These RAdio frequency instruments are called "ground penetrating radar (GPR). At low frequencies, the effective penetration can be much larger, several thousand meters, but electromagnetic waves diffuse slowly into the earth, rather than traveling in a straight line. Instruments operating at such low audio frequencies are called "ground conductivity meters."

Our innovative approach to GPR sensor technology with associated signal processing and post-processing software, which are summarized in this paper, uses step frequency signals based on the network analyzer principles instead of most commonly used impulse radar system. Therefore, a battery of network analyzers is used for signal transmission and subsequent acquisition of the return or reflected signals. Our evaluation of the existing UXO technology (Snyder and Rigano, 1995; Bakhtar and Sagal., 1998) coupled with survey of available GPR confirmed the need for a more refined system to fulfill the present and future requirements of the US military and civilian needs for UXO site remediation. The concept being developed is so advanced and unique in terms of operational characteristics and hardware that it can easily be referred to as the "next generation ground penetrating radar" (EarthRadar). The manner in which the overall system can be configured, in terms of hardware and signal processing and control software, makes it ideal for other applications such as mapping of subsurface geologic details, locating cavities and collapse features, identifying contaminated ground, locating depth of water table, etc.

As evident from recent studies reported by the US Army Environmental Center (Snyder and Rigano, 1995), it is feasible to develop a cost-effective, multi-functional, and user friendly remote sensing device for locating buried targets, i.e. missiles, bombs including cluster bombs, and hazardous chemical compounds. In a recent technical report, it was described how a repetitive and coherent electromagnetic wave (energy) can be generated and transmitted into the ground for sensing targets (Bakhtar, 1996). Furthermore, demonstrations were made (Bakhtar and Sagal, 1998) on the potential use of "tomography" to process and reconstruct an image from projection data or reflected signals. This paper summarizes the progress made on development of the Air Force EarthRadar for detection of buried UXO and describes the current capability as well as the technologies being developed for target-clutter discrimination and antennae design.

HARDWARE

The EarthRadar system architecture is illustrated in Figure 1. It is a multi-station sensor comprising of three basic units. A “basic unit” is defined as a network analyzer connected to an acquisition and control computer, via a GPIB interface, and the corresponding antennae.

On its own, a basic unit should be capable of field operation if approximate depth of the target to be detected is known. However, advance pre-tuning of the system for that depth region will be required. But, when the target depth regions are completely unknown or their density distribution is over a wide range, a multi-station system will be required. Figure 2 shows the schematic of the EarthRadar system. The antenna performance and characteristics of the transmission line (TL) are very important to meet the overall system and ground compatibility requirements.

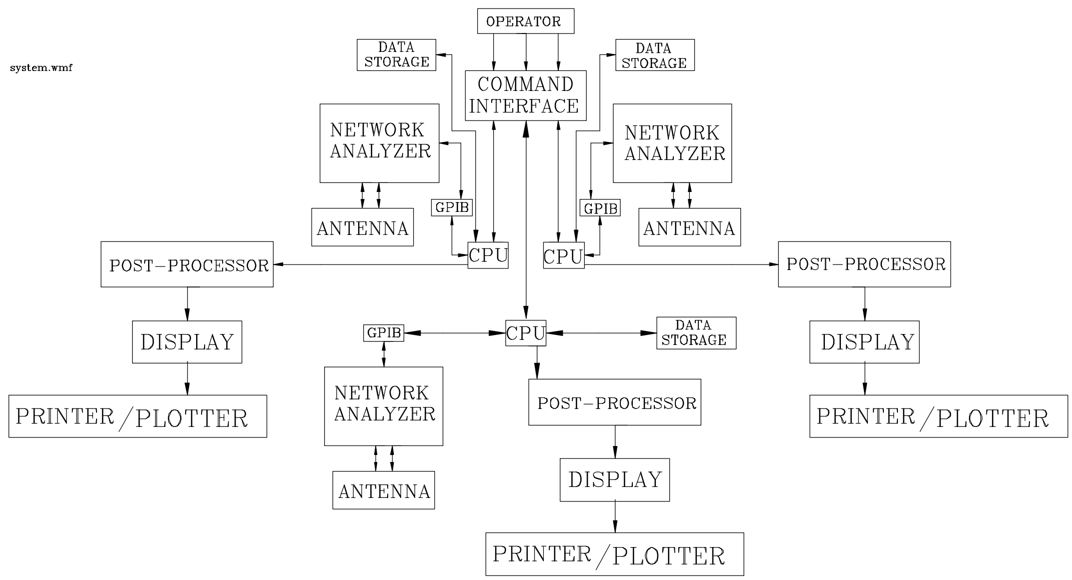

FIGURE 1 - EarthRadar SYSTEM ARCHITECTURE.

For detection of ordnance ranging in size from 5-cm to 200-cm or longer (with aspect ratios from 2 to 10) and target depth range of 0.05-m to 50-m, a combination of three basic units (with three different antennae) may be needed as explained below:

(a). The first unit may use a frequency range 500 - 1500 MHz, Horn, TEM horn, or di- pole antennae. At these microwave frequencies (>300MHz) the antenna separation can be about 0.2-m and mounted in the front of a moving platform. Special provisions can be incorporated to adjust the separation distances between antennae and ground for signal optimization that detect targets in a depth range of 0.1to 1.0m.

(b). The second system may use dipole antennae with a frequency range of 100 to 500 MHz. The antennas 1.5-m apart and placed at the back of the moving platform to detect targets in the depth region of 1.0-m to 10.0-m.

(c). The third unit may use a frequency range of 10 to 100 MHz, dipole antennas, with the antenna separation at 5-m. They are placed at each side of the moving platform to detect targets in the depth r 10.0- to 50-m.

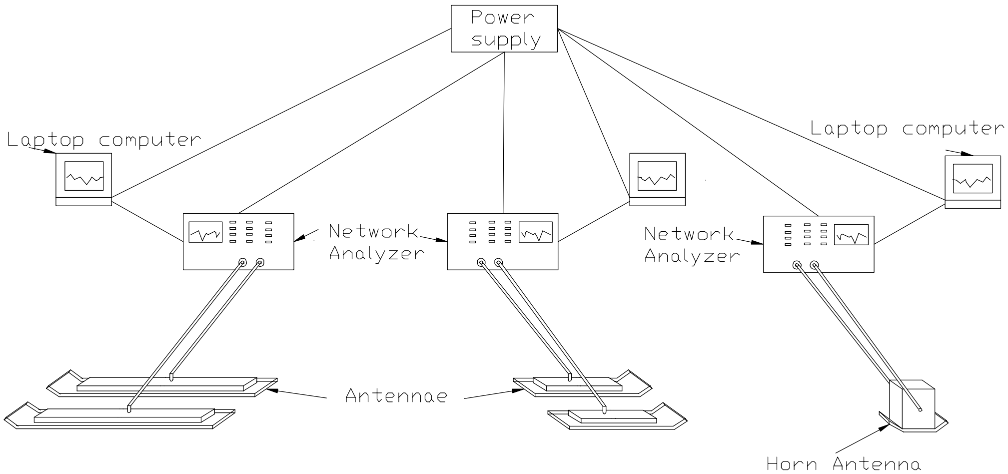

Figure 2 - Air Force Multi-Station UXO Sensor (EarthRadar).

The above configuration can be changed (replacing antennae with different characteristics) to meet different site, target size, and depth region conditions. For the EarthRadar, the electric properties of the ground control propagation of the electromagnetic waves; **permittivity** (ε) controls wave speed and **permeability** (μ) determines the signal attenuation. The EarthRadar system detects reflected or scattered energy which is created by changes in the electromagnetic impedance associated with variations of the material properties as a function of spatial locations below the earth surface. Physical properties of the medium through which detection measurements are performed are by far more important for RF signals than the other properties such as chemical or mechanical. Radar reflections are induced when the RF signals (RAdio waves) encounter a change in velocity attenuation associated with a change in medium. The bigger the variation in properties, the stronger the reflected signals.

CONTROL-ACQUISITION AND PROCESSING SOFTWARE

The ***EarthRadar*** software was written to run on a PC in the Microsoft Windows environment using the LabWindows development system for C programmers. This platform was chosen, as it contains libraries of functions which aided in creating data acquisition and instrument control panels and control routines. It also contains an interactive environment in which to develop graphical user interfaces (GUI) and a library of functions to assist in signal processing. The programming environment will accept standard C language programming, so it is convenient to modify or add program software features. This is an important feature, because different techniques for signal display and processing can be easily implemented and tested.

Under field operation, real time reflected signals can be displayed in color, wiggle, and grayscale formats. Post-processing algorithms, such as edge detection, linear contrast expansion, and binary thresholding, enhance the ability for buried target detection and location.

FIELD TESTS

A summary of field tests conducted using EarthRadar system is provided in Table 1. Field investigation, test and system performance evaluation were initiated in April 1996. Initial field tests associated with fine-tuning of EarthRadar hardware, validation of acquisition and control software, and overall system performance were conducted at the Naval Air Warfare Center (NAWC) in China Lake, California.

Several of the tests listed in Table 1 was conducted to locate and retrieve live bombs. Also, on May 19, 1998 a series of detection tests were successfully on submerged targets in Ocean water containing high salinity. Both metallic and plastic targets were used for this exercise.

RESULTS

Reflected signals from a 155 mm buried projectile (target) are used to provide examples of detection capability of the EarthRadar system. Figures 3 to 6 show the returned signals in wiggle, color, threshold, and edge detection formats.

ON-GOING AND FUTURE WORK

Testing the ability to detect targets buried in different types of soil is almost completed. The on-going work include (i) development of site specific antennae for optimal performance of the EarthRadar system, and (ii) development of reflection tomography, 3-D image reconstruction for target discrimination. (iii) integration of a differential global positioning system (GPS) with EarthRadar for location identification. The GPS will also provide the elevation data which is needed for 3-D image reconstruction. It is anticipated that the successful completion of this program will enhance our ability to locate buried UXO in a cost-effective and safe manner.

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Bakhtar, K., “Results of Initial Field Demonstration on Buried UXO Detection,” Progress Report to US Air Force, Eglin AFB, Florida, Contract No: F08626-C-95-0233, May 1996.

Snyder, G. and Rigano, K., “System/Design Trade Study Report for the Navigation of the Airborne, Ground Vehicular and Man-Portable Platforms in Support of Buried Ordnance Detection, Identification, and Remidiation Technology,” US Army Environmental Center, Report No: SFIM-AEC-ET-CR-95043, March 1995

Table 1 - Summary Of Field Tests Conducted Using EarthRadar.

TEST BED LOCATION	TARGET TYPE (DATE)	NUMBER OF TARGETS
Open Area Naval Air Warfare Center	155 mm Projectile (April 16, 1996)	1
Cactus Flat Range* Naval Air Warfare Center	Mark 84 (April 23 - 24, 1997)	1
Cactus Flat Range* Naval Air Warfare Center	Mark 82 (April 23 - 24, 1997)	9
Cactus Flat Range* Naval Air Warfare Center	PMN-2 Anti-Personnel Mine VS 2.2 Anti-Tank Mine TS-50 Anti-Personnel Mine (April 24, 1997)	1 1 1
White Sands Missile Range++	BLU 113 (Experimental) (July 9, 1996)	1
White Sands Missile Range++	BLU 109 (Live Weapons) (July 11, 1996)	2
Lower Mesa** Wright Laboratory Test Site Tyndall Air Force Base	150-mm, 105-mm, Bomb Fragments, Barbed Wires, Angle Iron, etc. (July 19 – 25, 1997)	96
Upper Mesa** Wright Laboratory Test Site Tyndall Air Force Base	Large Bombs and Missiles (July 19 – 25, 1997)	29
Lower Mesa** Wright Laboratory Test Site Tyndall Air Force Base	Buried Flat Plate GPS Integration Exercise (August 12 - 19, 1997)	1
El Toro Marine Base Orange County, California	Buried 40 mm Projectile – December 3, 1997	1
El Toro Marine Base Orange County, California	Buried 40 mm Projectile – January 14, 1998	1
El Toro Marine Base Orange County, California	Buried 40 mm Projectile – January 20, 1998	1
Utah Test and Training*** Range (UTTR), Utah	MK82 Penetrator Weapons – January 6, 1998	4
Dugway Proving Ground, ***Utah	MK82 Penetrator Weapons – January 7, 1998	1
Del Mar Harbor**** Camp Pendleton, California TESTS CONDUCTED ON MAY 19, 1998	20 mil metal can - 20-in dia barbel VS 1.6 and VS 2.2 Italian Anti-Tank Mine TS 50 Italian Anti-Personnel Mine PMN-2 Russian Anti-Personnel Mine	1 - 1 1 - 1 1 1

*** -** Adverse soil conditions; high moisture content; salt content = 7.03 gm/liter.
++ - Adverse soil conditions; clayey interbedded cliché materials.
** - Sugar-sandy with occasional clay lenses. *** - Salt-Saturated Clayey Soil
**** - Submerged in Ocean Water Simulating Surf Zone

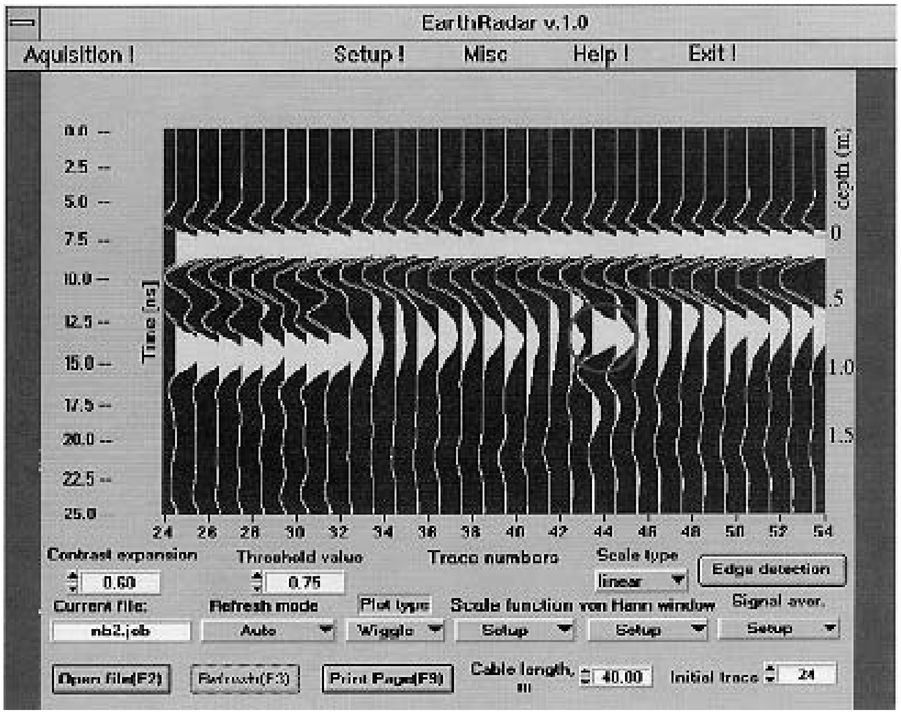

Figure 3 - Reflected Signal In Wiggle Format.

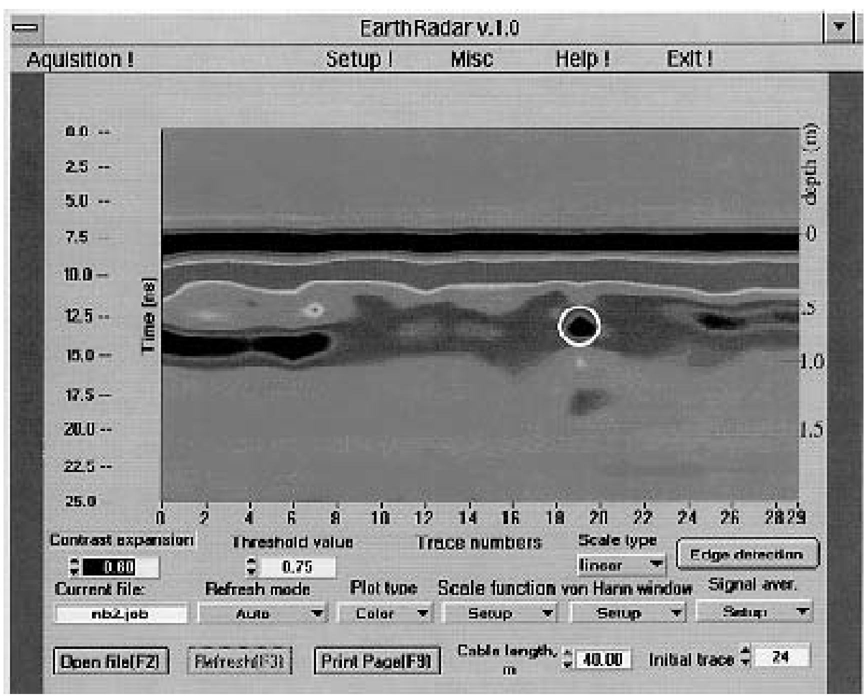

Figure 4 - Reflected Signal In Color Format.

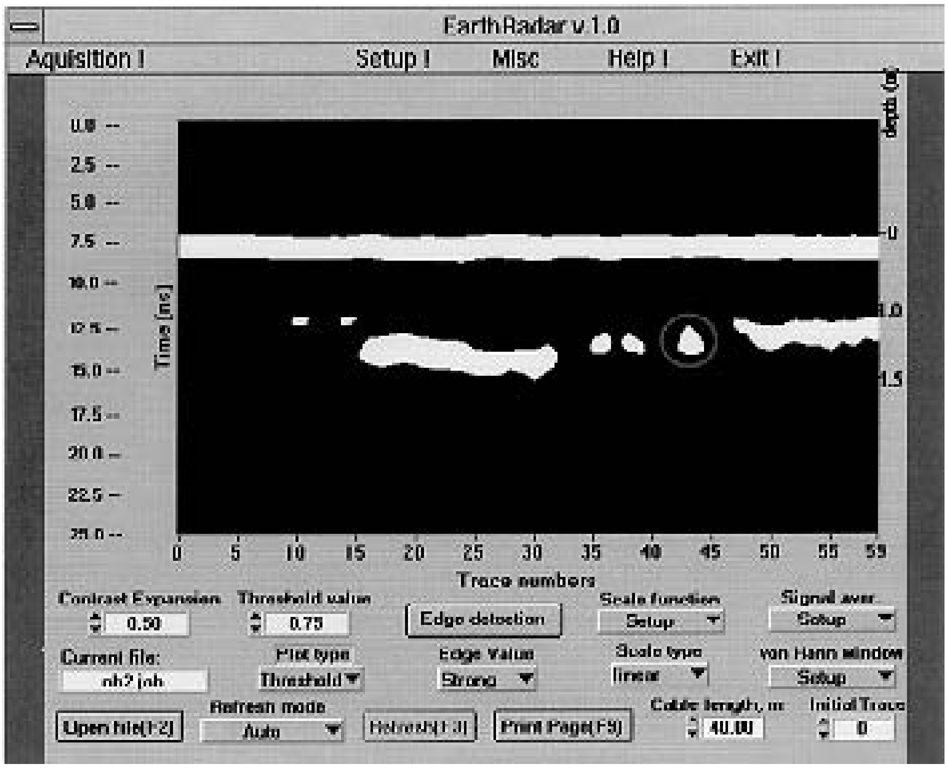

Figure 5 - Reflected Signal In Threshold Format.

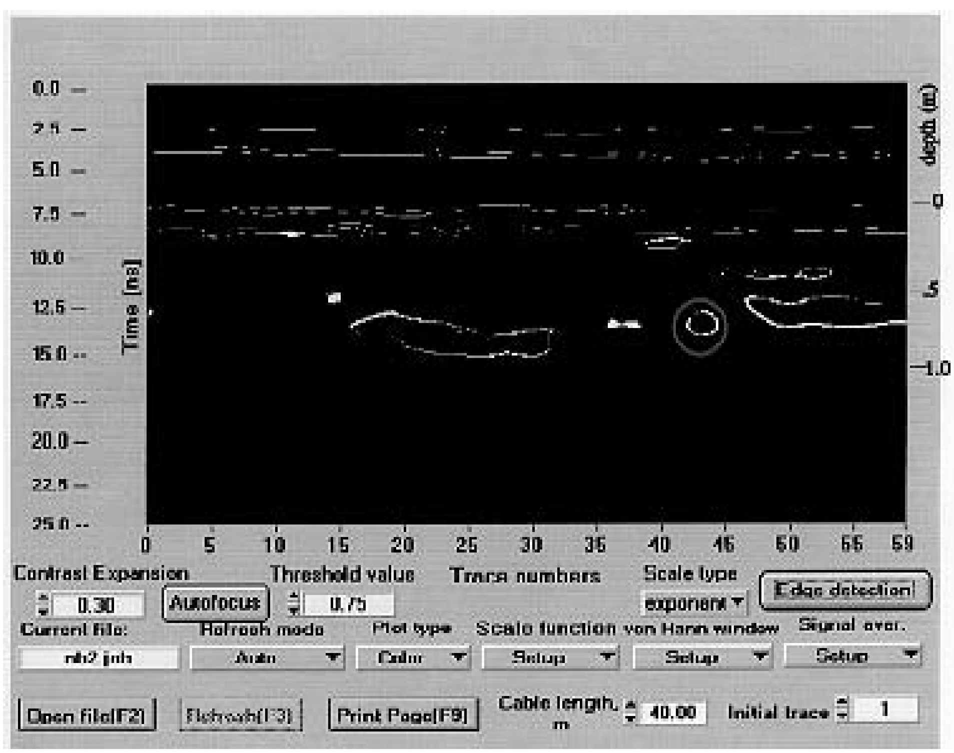

Figure 6 - Reflected Signal In Edge Detection Format.